SPECIFICATION

TITLE

"MULTI-CHAMBER PACING SYSTEM"

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a multi-chamber pacing system of the type having a pulse generator for successively delivering pacing pulses to chambers of a patient's heart, and evoked response detectors having blanking intervals following the delivery of pacing pulses and including sensing elements for sensing IEGM signals from each of the heart chambers and an integrating unit that integrates the IEGM signal within evoked response detection time windows after delivery of pacing pulses for detecting evoked response, the evoked response detection time window for a heart chamber containing at least one blanking interval resulting from delivery of a pacing pulse to another chamber, and each of the sensed IEGM signals having a generally known morphology.

In the following, "chambers of the heart" denotes right and left atria as well as right and left ventricles of the heart.

Description of the Prior Art

United States Patent No. 6,148,234 disclose a dual site pacing system, either bi-ventricular or bi-atrial, wherein signals are sensed during the refractory period following delivery of stimulation pulses. Pacing pulses are delivered substantially concurrently to both the heart chambers, although it is

mentioned that for patients with an intra-atrial block, the left atrium may be stimulated up to 90 msec later than the right atrium. If capture is achieved in both chambers no intrinsic depolarization signals can be generated during the following biological refractory period of the cells of he heart. If, however, the threshold of one heart chamber has risen above the level of the delivered pulses, that chamber will not be captured and will not have a biological (heart cell) refractory period following that delivery of the pulses. In this case, for patients having a conduction delay from one chamber to the other, the propagated signal from the other chamber will be sensed in the non-captured chamber during the pacemaker refractory period, that is started by the stimulation pulse delivered to the other chamber. Such sensing during the pacemaker refractory period is interpreted to be the result of loss of capture.

If two heart chambers are stimulated at somewhat different times, one of the chambers will be blanked when the other one is stimulated. Most pacing systems are constructed such that all signal channels are blanked when a stimulation pulse is emitted. Consequently there will be an interruption in sensed IEGM signals and that will influence the evoked response signals obtained by integration of the IEGM signals. This occurs in all dual or multi chamber pacing systems, e.g. at both bi-ventricular and bi-atrial pacing. If sensed signals are integrated in an evoked response detection time interval from e.g. 4 msec to 50 msec after stimulation to determine evoked response, and if a stimulation of the other chamber takes place at 10 msec after the first stimulation, there will be an interruption of the signal in the above mentioned detection time interval.

SUMMARY OF THE INVENTION

An object of the present invention is to provide an improved technique for detecting evoked response in a reliable way for multi-chamber pacing.

This object is achieved by a pacing system of the type initially described wherein the integral of the IEGM signal sensed in one heart chamber during blanking intervals resulting from stimulation in other chambers is reconstructed. The reconstructed integral normally will differ somewhat from the true integral value without blanking, however, this will result in errors of only minor importance and will not negatively influence the possibility of detecting evoked response on chambers having stimulation blankings. When reconstructing the integral of the signal the knowledge of the general signal morphology is utilized. To be able to reconstruct the integral the second pacing pulse in a pair of consecutive pacing pulses must not be delivered within the blanking interval following the first pacing pulse. The pulse generator is therefore controlled to deliver the second pacing pulse with a time delay exceeding the length of the blanking interval following the first one of the two consecutive pacing pulses. It should also be noted that with the present invention it is also possible to reconstruct the integral in more than one blanking interval, occurring in an evoked response detection time interval as a result of subsequent stimulations in other chambers of the heart. Such a situation can appear if time delays between the stimulations in different heart chambers are comparatively short.

In an embodiment of the pacing system according to the invention the signal reconstructing unit selects among several predetermined ways of reconstructing the IEGM signal in the blanking interval with the aid of the

knowledge of the signal morphology. This way knowledge about the signal morphology is utilized for selecting the best way of reconstructing the signals in the blanking interval.

If a constant signal level u_0 equal to the mean value of the sensed IEGM signal values at the beginning u_1 and at the end u_2 of the blanking interval is integrated during the blanking interval, the result may be somewhat noise-sensitive, since it depends only the two samples u_1 and u_2. To reduce this noise sensitivity, in another embodiment of the pacing system according to the invention, a filter is provided to filter the IEGM signal in a filtration time interval of predetermined length to produce a reconstructed signal for use for detection of evoked response, the filtration time interval containing the blanking interval.

In another embodiment of the pacing system according to the invention, the pacing system includes an implantable lead having a tip electrode and a ring electrode and the pulse generator has a case, and IEGM signals are measured between the tip electrode and the case and between the ring electrode and the case, respectively. A memory is provided for storing the IEGM signals, and the integral reconstructing unit integrates the IEGM signal measured between the tip electrode and the case while using that portion of the stored ring electrode-to-case IEGM signal which corresponds to the blanking interval in the integrated IEGM signal for the integration within the blanking interval. Even though the ring electrode may be floating in blood and the tip electrode attached to the myocardium and the tip and ring electrodes have different shapes, the signals will look quite similar. Because the unipolar evoked response (ER) signal originates from the tip

electrode and spreads out in the myocardium, it passes the ring electrode a short time later. Thus the ring electrode-to-case signal will be delayed compared to the tip electrode-to-case signal. If a tip-to-case signal channel is blanked during the evoked response detection time window, information about the signal in this blanking period can be found in the ring-to-case signal after a certain time when none of the two signal channels are blanked.

DESCRIPTION OF THE DRAWINGS

Fig. 1 is a basic block diagram of an embodiment of a pacing system according to the invention.

Figs. 2-5 schematically illustrate IEGM signal portions containing a blanking interval for explaining different reconstructing techniques suitable for use in the pacing system according to the invention.

Fig. 6 is a flow chart for an example of evoked response signal processing during blanking in the pacing system according to the invention.

Fig 7 illustrates another embodiment for reconstruction in the pacing system according to the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 schematically shows a multi-chamber pacing system with leads 42, 44 , 46 having bipolar electrodes 48, 50, 52 implanted in right atrium and in the ventricles of a patient´s heart 54. The pulse generator case is schematically shown at 56.

Inside the pulse generator case there are an evoked response detector 58 with IEGM signal sensing circuitry and an integral reconstructing unit 60 and a memory 62 . The evoked response detector 58 either can be

composed of multiple evoked response detectors for the respective multiple chambers that are paced, or can be considered as a single evoked response detector having multiple channels for the respective multiple chambers that are paced. These components are preferably realized by a microprocessor.

For each of the multiple chambers this is paced IEGM signals are sensed and integrated by the evoked response detector 58 in an evoked response detection time window. The integral reconstructing unit 60 reconstructs the integral in blanking intervals resulting from delivery of pacing pulses in other heart chambers. In the memory 62, measured complete IEGM signals are stored, such that the reconstructing unit 60 can use that portion of the stored signal that corresponds to the blanking interval. A complete IEGM signal can be measured in advance and stored in the memory 62. IEGM signals alternatively can be measured simultaneously between tip electrode, e.g. the tip electrode 64 in the right ventricle and the case 56, and between said ring electrode 66 in the right ventricle, and the case 56. The measured IEGM signals are stored in the memory 62. Since the ring-to-case signal is delayed relative to the tip-to-case signal, the integral reconstructing unit 60 integrates the IEGM signal measured between the tip electrode 64 and the case 56 while using that portion of the stored ring electrode 66-to-case 56 IEGM signal which corresponds to the blanking interval in the integrated IEGM signal.

Figure 2 shows qualitatively the simplified appearance of an intracardiac evoked response signal as a function of time following the delivery of a stimulation pulse 2. A blanking interval 4, resulting from the

delivery of a pacing pulse in another heart chamber, is limited by two vertical dashed lines 6,8 in Figure 2. The blanking time is normally 6-15 msec.

Figure 3 shows in an enlarged scale a portion of the intracardiac evoked response (ER) signal in Figure 2. Figure 3 illustrates an example where the ER signal during the blanking interval 4 is mathematically reconstructed by using the instant slope at the starting point 10 of the blanking interval. The reconstructed signal is then used for reconstructing the integral of the signal.

Figure 4 shows an example with the blanking interval 12 positioned around a minimum 14 in the intracardiac ER signal. In this embodiment the signal is reconstructed in the blanking interval by using the instantaneous slopes of the intracardiac ER signal at the beginning 16 and end 18 of the blanking interval 12 for linear extrapolations of the signal forwardly from the beginning 16 of the blanking interval 12 and rearwardbly from the end 18 of the blanking interval, respectively. This linear extrapolations meet in an intersection point 20, thus forming a reconstructed signal in the blanking interval 12. . The reconstructed signal is then used for reconstructing the integral of the signal.

As another alternative the intracardiac evoked response signal can be reconstructed or replaced during blanking by a constant signal level u_0 , e.g. equal to the mean value of the signal values u_1 and u_2 at the ends of the blanking interval 22, see Figure 5.

Instead of linear approximations of the signal within the blanking period as described above the signal can be reconstructed by applying a

polynomial of suitable degree to the signal by using a plurality of IEGM signal samples preceding and succeeding the blanking interval.

As can be seen from Figures 2 – 5 the ER signal is smoothly varying with time without any discontinuities, and the general morphology or progress of the signal in the evoked response detection time interval can e.g. be determined in advance by introductory measurements and memorized for the subsequent use, cf. the description of Figure 1 above.

Figure 6 is a flow chart illustrating an example of signal processing during blanking in the pacing system according to the invention. It is assumed that the evoked response signal processing occurs in e.g. a microprocessor controlled signal process known in the art. The example relates to normal autocapture signal processing just interrupted during blanking caused by stimulation in the heart chamber opposite to the considered chamber. The process disclosed in Figure 6 will replace the process, which would otherwise occur in autocapture signal processing if no blanking had occurred. The input to the flow chart in Figure 6 is the intracardiac evoked response signal integrated up to the beginning of the blanking interval or blanking point. The flow chart then illustrates the signal processing up to the end of the blanking interval whereafter the integrated evoked response signal is further processed in the normal, well-known way for evoked response detection.

VBLNK (see 24 in Figure 6) denotes ventricular blanking. Cnt in box 26 in Figure 6 denotes counter value, and U_{int} denotes integrated ER signal.

In box 28 U_{int} is integrated during VBLNK. The counter value equals the count number of loops, viz.the number of samples during VBLNK.

Box 30 illustrates the addition of the integrated value of estimated mean value of the signal during VBLNK to the integrated ER signal U_{int} up to the beginning of VBLNK.

The resulting evoke response signal $U_{evoked\ response}$, box 32, is then further processed, at 34, for evoked response detection according to well-known technique.

Another way of viewing the procedure illustrated in Figure 6 is to view the samples in the ER window as a mathematical vector. By taking the dot product of this vector and the vector whose samples are depicted in Figure 7 $U_{evoked\ response}$ is obtained. Given the definition of the product, the value of the integrated linearly interpolated evoked response equals

$$U_{evoked\ response} = \sum_{I=1}^{N} u_i \cdot f_i$$

where u_i are the individual voltage samples in the ER window and f_i the (filter) coefficients depicted in Figure 7.

The value of the filter coefficients immediately preceding and immediately succeeding the blanking period is equal to 1 + n/2, where n is the number of samples being blanked.

Although modifications and changes may be suggested by those skilled in the art, it is the intention of the inventor to embody within the patent warranted hereon all changes and modifications as reasonably and properly come within the scope of his contribution to the art.